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Influence of Substrate Proximate Properties on Voltage Production in Microbial Fuel Cells

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Abstract

In the current study, we investigate the influence of proximate properties of five different fruits on voltage and current generated from a double chamber microbial fuel cell. Fruits comprising of avocado, tomato, banana, watermelon and mango were analyzed for proximate properties using standard methods. Rumen fluid was used as the inoculum in fabricated H-shaped double chamber fuel cells with graphite rods electrodes at room temperature. The voltage and current generated were monitored daily for 30 days using a DT9205A digital multi-meter. The average moisture content for the fruits samples ranged from 82.86% - 95.16% while the crude fat was in the range of 0.12% - 0.33% with avocado having fat levels at 9.03%. Carbohydrates level was the highest in banana at 19.24% and the lowest in tomato waste at 2.93%. Tomato waste produced the highest voltage of 0.702 V on day 20 while lower voltage was noted in watermelon fruit wastes at 0.019 V. The voltage and current increased linearly with time for all the fruit wastes. These results indicate that substrate proximate properties influence the voltage and current generated in microbial fuel cell. In addition, moisture content and carbohydrates level were the major factors that influence microbial fuel cells performance.

Keywords

Voltage, Fruits Waste, Proximate, Current

1. Introduction

The primary factor that affects the performance of microbial fuel cells (MFC) is the substrate source. Various types of substrates are available for biomass-electricity production [1]. They range from simple to complex substrate matters in wastewater. Studies have been carried out to produce power using wastewater, different crop matter, cow manure, glucose and starch components of food, acetate, rice water, etc. [1]. Reference [2] experimented using 1 g/L acetate feed to generate power. They used familiarized MFC microbes and a single cube-shaped chamber of graphite fiber brush anode. It generated about 0.8 mA/cm^2 current density. Reference [3] in another study involving arbitol as a co-substrate in a single chamber, air-cathode MFC produced a current density about 0.68 mA/cm^2.

In a two-chamber air-cathode fuel cell, a study by [4] using 400 mg/ml phenol produced a current density of 0.1 mA/cm^2. A research study by [5] using a two-chamber MFC with woven graphite anode, ferricyanide catholyte and *Clostridium butyricum* generated 1.3 mA/cm^2 current density.

Reference [6] used urban wastewater of about 330 mg/ml in a two-chamber MFC and successfully generated current density of 0.018 mW/cm^2. In another study, [7] used food processing wastewater for a two-chamber MFC, having graphite electrode and generated a current density of 0.05 mW/cm^2. A study by [8] [9] using domestic wastewater of concentration of 600 mg/L in a two-chambered mediatorless MFC has graphite electrodes. The device generated a current density of 0.06 mW/cm^2. Reference [10] used cattle dung as a substrate for his MFC and was able to generate 0.22 W/m^3 of volumetric power density.

Reference [1], in an effort to dispose of food wastes (FWs) through a process of waste-to-energy, harnessed electricity of 556 mW/m^2 power density at carbon oxygen demand (COD) range of 3200 ± 400 mg/L with a maximum columbic efficiency (CE).

Reference [11] investigated power production from MFC using solid waste and cow dung. It involved a single and twin compartment types, recording a voltage of 0.38 V and 470 Ω resistance. The power density measured about 36.6 mW/m^2 in the presence of 20% platinum catalyst and Nafion. Reference [12] in a three-chamber MFC and bio-cathode test of electricity potential of cow dung produced a maximum voltage of 0.502 V across a 100 Ω external resistance and a power density of 8.15 W/m^3.

2. Materials and Methods

2.1. Fuel Cell Assembly

Double chamber microbial fuel cells were fabricated using locally available material like spent dry cell batteries graphite rods as electrodes, 1 litre plastic containers and copper wires. The assembly was done as described in [13] and a setup figure is shown in **Figure 1**.

2.2. Sampling

The rumen fluid used in this study was obtained from Dagoretti slaughter houses (1˚17'02.6"S 36˚41'02.2"E) in Kiambu County. The market wastes including vegetable and fruits wastes were obtained from Kangemi market (1˚15'52.9"S 36˚44'55.6"E) and Wakulima market (1˚17'13.3"S 36˚49'56.2"E) in Nairobi County. A map of the sampling sites is shown in **Figure 2**.

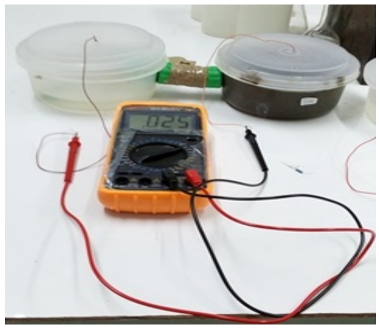

Figure 1. Double chamber microbial fuel cell setup [13].

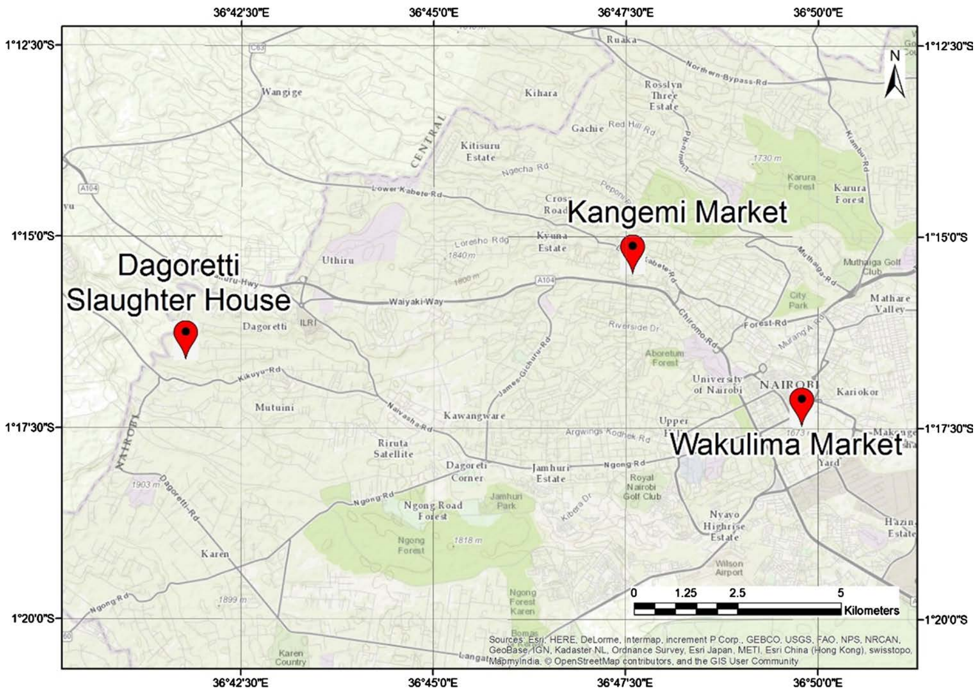

Figure 2. A map of the sampling points.

2.3. Proximate Analysis

The fruit wastes were washed to remove soil particles and then subjected to size reduction using a kitchen knife and blended before analysis. The ash, moisture and fiber contents were determined using AOAC method [14]. Fat, crude nitrogen and protein contents were determined using Soxhlet extraction and Kjedhal methods described in Pearson [15]. Energy content was carried out using the AOAC method described in [16] while total and volatile solids were determined using Renewable technologies method as described in [17].

2.4. Microbial Fuel Cells

The avocado, watermelon, banana, tomatoes and mango were thoroughly washed using tap water and rinsed using distilled water. They were sliced into small pieces using a kitchen knife. The wastes were blended using a kitchen blender with 500 ml of the blend being loaded into the anodic chamber of the fuel cell.

The inoculum (300 ml) rumen fluid was added to the anodic chamber and thorough agitated. The cathodic chamber was loaded with 800 ml of distilled water. Graphite-rods attached to copper wire were inserted in both chambers before sealing with a lid and a masking tape as described in [13]. A multi-meter was used to measure the voltage and current on daily basis for 30 days.

The experiments were run in triplicates and means and standard deviation are reported and further used to plot the graphs and curves using Minitab 17 and Microsoft Excel 2013 statistical applications.

3. Results

The proximate analysis involves analysis of crude proteins, fiber, fat, carbohydrates, moisture, ash, nitrogen-free extract and energy. **Table 1** shows the proximate properties of different fruits waste from Nairobi County. In a previous study, similar results were obtained by [18] who reported high moisture content in organic waste at a range of 73.69% - 98.66% for fruits wastes.

The moisture level was highest in tomato fruits and lowest in banana waste at the range of 74.30% - 95.16%. The crude fat level in avocado was 27 times higher than in watermelon. The carbohydrates level in the waste was analyzed buy difference method [19]. This means the subtraction of the sum of the other properties from 100. The carbohydrates and energy levels are shown in **Figure 3**.

The proximate properties compare well with previous studies as discussed,

Table 1. Proximate analysis properties for different wastes.

SAMPLE	% MOISTURE	% PROTEIN	% FAT	% ASH	% FIBRE	% NFE	ENERGY (Kcal/100 g)
Tomato	95.16 ± 1.23	0.57 ± 0.01	0.12 ± 0.02	0.46 ± 0.02	0.76 ± 0.04	15.08 ± 2.31	2.93 ± 0.01
Banana	74.30 ± 0.09	3.05 ± 0.05	0.51 ± 0.02	1.67 ± 0.05	1.24 ± 0.04	93.66 ± 5.62	19.24 ± 2.31
Avocado	82.83 ± 2.36	1.32 ± 0.01	9.03 ± 1.25	0.84 ± 0.03	2.61 ± 0.05	100.03 ± 3.66	3.37 ± 0.85
Mango	86.82 ± 0.84	0.87 ± 0.03	0.68 ± 0.05	0.44 ± 0.05	1.28 ± 0.05	49.24 ± 2.01	9.91 ± 0.96
Melon	92.85 ± 0.08	0.91 ± 0.02	0.33 ± 0.21	0.74 ± 0.04	0.76 ± 0.09	24.18 ± 1.55	4.42 ± 0.02

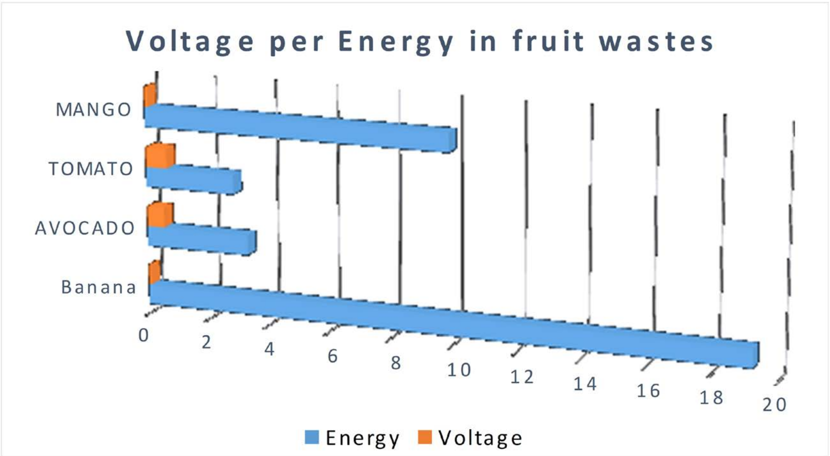

Figure 3. The % carbohydrates in different fruits wastes.

the moisture content on fresh tomato wastes was 95.16%. Previous studies [20] showed moisture content of 90.75% in tomato fruits. Moisture content reported in this study is slightly higher but in range with previous studies by [21] [22] [23] who reported moisture content in the range of 88.19% to 90.67%. Ash content represents the minerals remaining when moisture and organic matter are driven off from a sample. The ash content in leafy vegetables was higher compared to fruit wastes samples. For instance, the obtained ash content was between 2.06% to 2.46% for pig weed, pumpkin leaves, *Cucumis ficifolia* and highest in comfrey at 3.46%. Lower ash content was reported in wastes e.g. 0.46% in tomatoes. Avocado, mango and watermelon ash content were 0.84%, 0.44% and 0.74% respectively.

The energy obtained from different market wastes on as received basis is shown in **Figure 3**. It was the lowest in tomato and avocado. Levels in the wastes were calculated from the data on protein, carbohydrates and fats using factors of 4, 4 and 9 kcal/100g, respectively [24].

Figure 4 shows surface plots obtained by plots of daily voltage and current generated from different fruits and fruits mix. The voltage generated was highest in tomatoes followed by avocado. The highest voltage recorded was 0.701 V in tomato waste on day 20. Low voltage was witnessed in watermelon wastes.

The generated voltage was highest in tomato waste at 0.701 V followed by avocado at 0.584 V and lowest in watermelon at 0.019 V respectively. In all the fruits, the voltage increased from day 1 to 5 with fluctuations in some wastes thereafter. For most of the fruits, current and voltage increased linearly with time.

4. Discussions

This section describes the influence of the proximate properties on voltage and current produced for the various fruits. High moisture is vital in facilitating the formation of more electron-mobile solutions and promotes the transfer of electrons to the cathode in the MFC [25]. Reference [8] reported that moisture contents greater than 10% increase voltage output by more than 3-fold. This is evident by the results obtained in this study whereby the 12.33% difference in moisture content between tomato and avocado registered a voltage difference of 0.128 V. Similarly, the moisture difference between banana and tomato results in a voltage margin of more than 8.9 folds.

Development of optimal electrogenic biofilms in the MFCs is highly dependent on carbon source which greatly determines the microbial population [26] [27]. High carbohydrates levels translate to high voltage as witnessed in voltage recorded in day 10 for banana and watermelon at 0.126 V and 0.004 V respectively. This shows that carbohydrate difference of 14.82% results in more than 15 fold increase in voltage output. Carbohydrate serves as the major carbon source for microbial activities. In terms of energy, the observed trend is that the higher the energy of the fruit waste, the lower the voltage generated. A clear trend can be observed in **Figure 5**. This is explained by the fact the high energy substrate

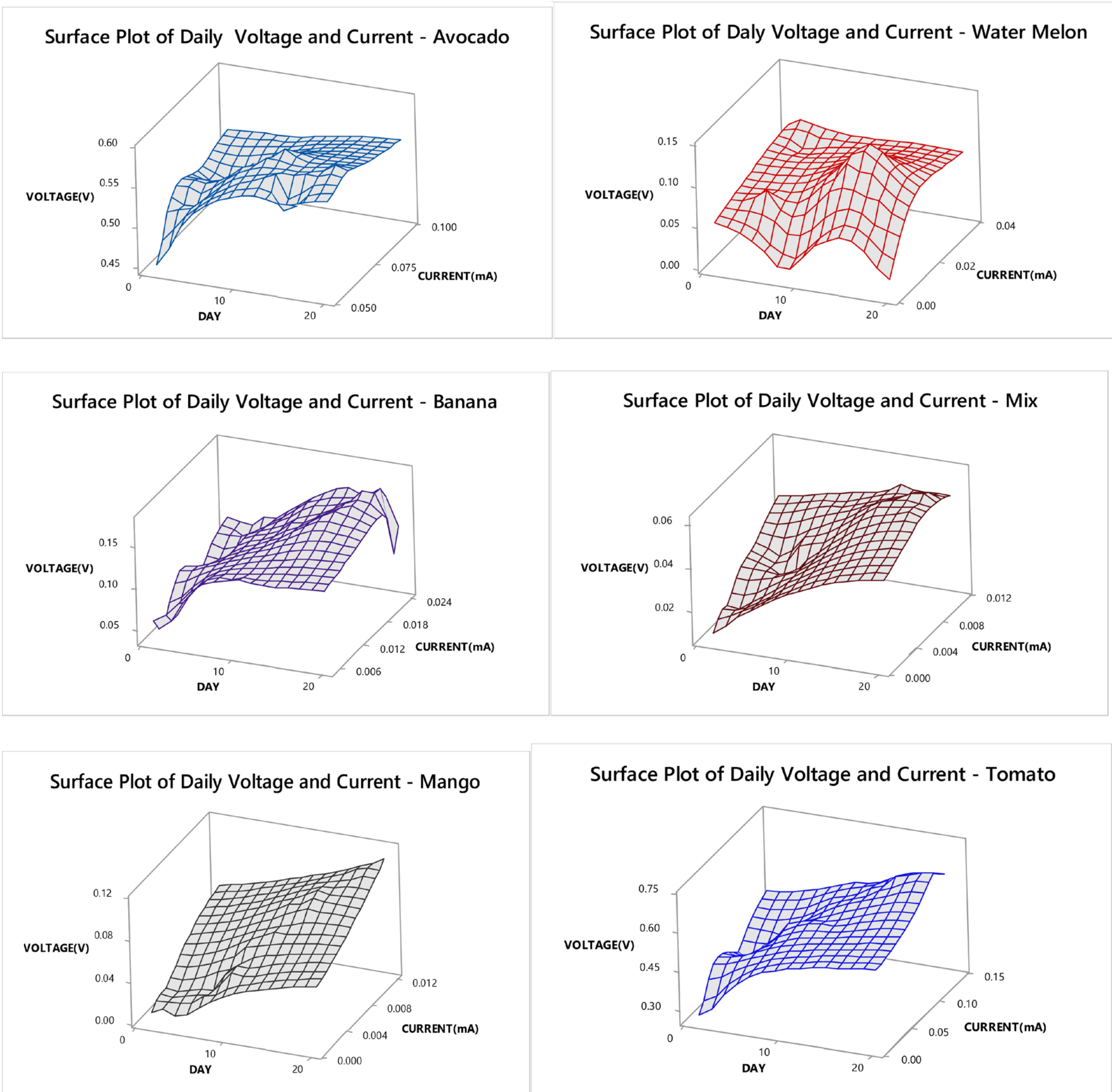

Figure 4. Surface plots of daily voltage and current generated from different fruits wastes.

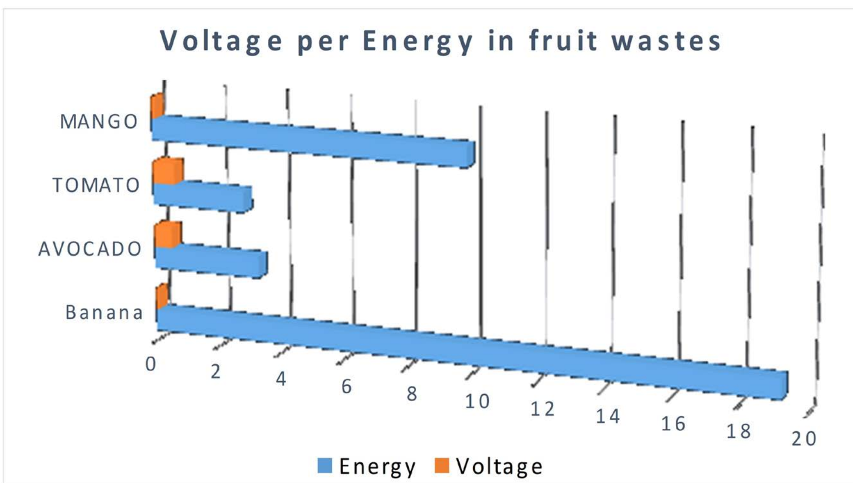

Figure 5. Bar graph of fruit energy levels versus voltage output.

requires high microbial activities (this explains high current recorded).

The influence of fat levels in the fruits wastes has no significant difference in the voltage generated. For instance, avocado fat levels are 9.92% while tomato waste has fat levels at 0.12%. The voltage difference is less than 0.022 on day 11 V. Using a substrate with double the protein levels results in a 2 fold increase in voltage generated [28].

5. Conclusion

This study concludes that proximate properties of substrates influence the current and voltage generation in a microbial fuel cell. Moisture levels and carbohydrates compositions are the primary proximate properties that influence the performance of microbial fuel cells. This study, therefore, recommends employment of high moisture and carbohydrate rich substrate to increase power production in microbial fuel cells.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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